(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 435 201 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
12.11.1997 Bulletin 1997/46

(51) Int Cl.6: G02B 6/12, G02B 6/34, G02B 6/16

(21) Application number: 90125112.4

(22) Date of filing: 21.12.1990

(54) **Optical waveguide embedded light redirecting and focusing bragg grating arrangement**

Anordnung zur Neuorientierung und Fokussierung von Licht unter Verwendung eines optischen Wellenleiter-Bragg-Gitters

Arrangement de réorientation et de focalisation de lumière utilisant un guide d'onde optique à réseau de Bragg

(84) Designated Contracting States:
DE FR GB

(30) Priority: 26.12.1989 US 456442

(43) Date of publication of application:
03.07.1991 Bulletin 1991/27

(73) Proprietor: UNITED TECHNOLOGIES CORPORATION
Hartford, CT 06101 (US)

(72) Inventors:
- Meltz, Gerald
Avon, Connecticut 06001 (US)
- Morey, William Wayne
West Hartford, Connecticut 06117 (US)
- Wilson, Arnold Leroy
Bolton, Connecticut 06043 (US)

(74) Representative: Klunker . Schmitt-Nilson . Hirsch
Winzererstrasse 106
80797 München (DE)

(56) References cited:
EP-A- 0 282 878 US-A- 4 687 286

- SOVIET TECHNICAL PHYSICS LETTERS. vol. 15, no. 6, June 1989, NEW YORK US pages 459 - 460; A. S. SVAKHIN ET AL.: 'Focusing grating on a fiber and method of
- fabrication'

EP 0 435 201 B1

Printed by Jouve, 75001 PARIS (FR)

Description

The present invention relates to optical waveguides in general, and more particularly to a light redirecting and focusing grating optical waveguide as well as to a method of forming an embedded optical light redirecting and focusing grating in a selected region of an elongated solid portion of an optical waveguide.

There are already known various constructions of optical waveguides, including optical fibers, that are provided with embedded gratings that are being used either for inserting light into or for removing light from the respective optical waveguide at an intermediate location or at different intermediate locations of the waveguide. So, for instance, document US-A-4,749,248 discloses a device for tapping radiation from, or injecting radiation into, a single mode optical fiber. This patent discloses that it is possible to convert a guided mode in an optical fiber into a tunnelling leaky mode or vice versa by forming a grating of appropriate periodicity at least in the core of the optical fiber, and either to remove the guided mode from the fiber core into the cladding by converting it into the leaky mode, and ultimately from the fiber altogether, or to insert light of an appropriate wavelength into the core to form a guided mode therein by directing light of a proper wavelength from the exterior of the fiber toward the grating to propagate in the fiber cladding and to be converted by the grating into the guided mode in the fiber core. It is disclosed in this patent that the grating may be formed mechanically or by exploiting the photoelastic or photorefractive effect;.in either case, the grating is formed in such a manner that fiber core regions of identical optical properties are situated in planes oriented normal to the longitudinal axis of the optical fiber.

While this approach may achieve satisfactory results for some applications, it has an important disadvantage in that it results in very high losses of optical power coupled out of or into the optical fiber. This is at least partially attributable to the fact that, inasmuch as the grating is imposed normal to the longitudinal axis of the core, the conversion of the guided mode into the leaky mode or vice versa takes place with uniform distribution all around the fiber axis, so that a predominant proportion of the leaky mode is not captured by the sensing arrangement when this approach is being used to tap light out of the fiber, or bypasses the fiber core when this approach is being used to launch light into the core via the cladding mode and its conversion into the guided core mode at the grating.

It is also already known, for instance from document US-A-4,725,110 to impress periodic gratings into the optical fiber core by exposing the core through the cladding to the interference pattern of two coherent ultraviolet light beams that are directed against the optical fiber at two angles relative to the fiber axis that complement each other to 180°. This results in a situation where the grating is oriented normal to the fiber axis so that it reflects, of the light launched into the fiber core for guided propagation therein in a propagation direction, only that having a wavelength within a very narrow range, back along the fiber axis opposite to the original propagation direction so that such reflected light is guided in the core to the point at which the original light had been launched into the fiber core. On the other hand, this grating is transparent to light at wavelengths outside the aforementioned narrow band so that it does not affect the further propagation of such other light. It may be seen that this approach has its limitations as well in that it is not suited for removing meaningful amounts of light from or launching them into the fiber at any other location than the respective fiber ends.

This problem has been addressed in a commonly owned copending U. S. patent application Serial No. 07/456,450 issuing to document US-A-5,042,897. The solution presented there involves writing the grating elements at an oblique angle relative to the longitudinal axis of the waveguiding region, such as of a fiber core, so that the thus formed grating redirects light between a first path extending longitudinally of the waveguiding region, and at least one second path extending between the grating and the exterior of the waveguide in a direction that depends on the axial wavenumber or wavelength of the light being so redirected. This second path is shown to have a dimension as considered in the longitudinal direction of the waveguide that substantially corresponds to the associated dimension of the grating, and an external lens is being used in the second path to either focus the light emanating from the fiber or to collimate light issued by an external source onto the grating, depending on whether the grating is being used to tap light out of the waveguide or launch light into the waveguide. It will be realized that the need for providing such a lens, which typically has a complex configuration and thus is quite expensive, significantly increases the cost of the equipment and thus detracts from the commercial appeal of such equipment. Moreover, alignment problems may be encountered either during the initial set-up or during the operation of the equipment.

From prior art document US-A-4,687,286 a method of and an apparatus for optical spatial scanning have come to be known. A chirped grating focuses guided waves to variable space points as determined by the intensity of a control beam. This can be achieved with a light controlled spatial scanner which includes a corrugated waveguide. This waveguide has corrugations with a period that varies linearly from a first period at one point to a second period at another point, the first period being greater than the second one. Guided modes of light are applied within the waveguide in direction from the one point to the other point wherein the corrugations couple light from the guided modes to radiation modes focused at a focused spot in space.

This document neither discloses grating elements being embedded in a waveguide according to the invention neither grating elements extending at an oblique angle relative to the axis of the waveguide.

From document EP-A2-0,282,878 an arrangement for an optical spec trometer and a method of fabrication thereof has come to be known. This arrangement comprises an aperiodic grating where the waveguide is curved, thereby causing the light to be reflected out in an angular fashion.

Said document neither discloses nor suggests the use of an embedded grating having grating elements extending at an obligue angle relative to the axis of the waveguide.

Accordingly, it is a general object of the present invention to avoid the disadvantages of the prior art.

More particularly, it is an object of the present invention to provide an optical waveguide with an embedded light redirecting arrangement which does not possess the disadvantages of the known arrangements of this kind.

Still another object of the present invention is to develop the light redirecting arrangements of the type here under consideration in such a manner as to obtain highly efficient coupling of light at a selected wavelength within a limited range between the optical waveguide core and a spatially limited path extending externally of the core and passing through a focus or focal region.

A concomitant object of the present invention is to develop a method of forming the embedded tap in the optical waveguide core, which method is highly efficient and reliable.

These objects are solved according to the invention by a light redirecting and focusing grating optical waveguide according to the features set out with claim 1 as well as by a method of forming an embedded optical light redirecting and focusing grating exhibitting the features as set out in claim 3 Claim 2 exhibits further improvements of subject-matter of claim 1.

An optical waveguide light redirecting arrangement includes an optical waveguide having two spaced end portions, and including at least a waveguiding portion of a solid material capable of guiding light between the end portion in a first path extending along a predetermined axis. At least one grating region is embedded in the waveguiding portion at a location remote from the end portions, and has a multitude of grating elements extending at such spacings relative to one another as considered in the direction of the axis and at such oblique angles relative to the axis to redirect light reaching the grating elements between the first path and at least one second path extending externally of the waveguide and diverging between a focus and the grating region. There is further provided first optical means for directing light into one of the first and second paths and toward the grating region for redirection by the grating elements into the respectively other of the second and first paths with attendant in-phase combination in the other path of light having a wavelength within a range around a central wavelength, and second optical means for capturing the light propagating in the other path.

A method of producing the grating region involves the exposure of the waveguiding portion to the interference pattern of two coherent ultraviolet radiation beams, where the angles of these beams with respect to the longitudinal axis of the waveguiding portion at the center of the grating region are selected in such a manner that the interference pattern fringes (e.g. intensity peaks) extend through the waveguiding portion at the aforementioned oblique angle and induce permanent variations in the refractive index of the waveguiding portion in dependence on the intensity of the fringes, thus forming the aforementioned grating elements. One of the interfering beams may have a curved phase front, or the grating region may be bent either during the formation of the grating, or during its use, to cause the grating elements to have the aforementioned focusing effect. Another series of refractive index variations may be imposed orthogonally to the first one for the grating to focus to a focal point.

The present invention will be described in more detail below with reference to the accompanying drawing in which:

Figure 1 is a considerably enlarged axial sectional view of an optical fiber provided with an embedded grating region in accordance with the present invention for use in redirecting light into or out of the fiber core with passage of such light through a focus external of the fiber;

Figure 2 is a view similar to that of Figure 1 but showing the optical fiber as extending in a curved course during the formation or use of the grating region;

Figure 3 is a view similar to that of Figure 2 but showing an arrangement employing two of the fibers of Figure 2 arranged oppositely to one another and one issuing light into and the other receiving light from a focal region thereof;

Figure 4 is a considerably enlarged partially broken away perspective view of a waveguide provided with a grating formed by two orthogonal systems of refractive index variations to have a focal point for its focus; and

Figure 5 is a graphic representation of the dependence of the change in the refractive index on distance from the center of the waveguide, taken on line A - A of Figure 4.

Referring now to the drawing in detail, and first to Figure 1 thereof, it may be seen that the reference numeral 10 has been used therein to identify an optical waveguide. The optical waveguide 10 is shown to be configured as an optical fiber core, of which only a relatively short longitudinal portion is depicted. If so desired, a non-illustrated fiber cladding could be arranged, as is well known in the optical fiber field, around the fiber core 10. The fiber core 10 incorporates a grating region 11 that includes a multitude of grating elements 12.

At this juncture, it may be appropriate brierly to describe the arrangement disclosed in the aforementioned docu-

ment US-A-5,042,897, as much of which as needed to fully appreciate and/or understand the present invention is incorporated herein by reference, so as to aid in understanding the problem with which the present invention successfully deals. In that arrangement, each of the grating elements extends at substantially the same oblique angle α with respect to the longitudinal axis of the core, and the grating elements are spaced the same distance from one another as considered in the longitudinal direction of the optical fiber. The grating elements are formed in the grating region of the core, which is preferably of a germanium-doped silica or similar glass that is capable of having the grating elements written, impressed or otherwise applied or embedded therein, by application of an interference pattern of two ultraviolet radiation beams to the core. The thus produced periodic grating elements then constitute refractive index perturbations that are permanently induced in the core by exposure to ultraviolet radiation. This method makes use of a first order absorption process in response to transverse irradiation of the fiber 10 with light in the ultraviolet absorption band of the core material. Inasmuch as the grating is formed by illuminating the core from the side, preferably through the cladding and without affecting the latter, with two coherent beams that are incident on the optical fiber symmetrically to a plane extending at the oblique angle α with respect to the longitudinal axis of the core, the intensity peaks of an interference pattern resulting from interference of the coherent incident beams, and thus the grating elements, extend parallel to this plane and the spacings between the grating elements are the same. Such exposure induces permanent refractive index changes in the grating region, in effect creating a phase grating effective for redirecting light reaching the grating.

While only a quite small portion of the light propagating through the fiber core or being launched into the core is redirected at each of the grating elements as a result of the refractive index changes attributable to the presence of the grating elements, subsequently to either leave the optical fiber or to be launched into the core for guided longitudinal propagation therein, respectively, the cumulative effect of the grating elements is the redirection of a significant proportion of the light the wavelength of which is in a very narrow range around the center wavelength λ that is in a predetermined ratio to the periodicity of the grating elements. Furthermore, the light within the narrow range that is thus redirected at any one of the grating elements out of the optical fiber is in such a phase relationship with respect to the light redirected at any other of the grating elements that the cumulative redirected light beam has a substantially planar wavefront so that substantially none of the thus escaping redirected light is lost to destructive interference or diffraction. Moreover, the thus escaping redirected light beam propagates outside the optical fiber along a single direction determined by the aforementioned oblique angle α, albeit with some fanning out in the circumferential direction, rather than all around the optical fiber; this facilitates the capture of the thus escaping light and increases the proportion of such light that is actually captured.

By the same token, when coherent light is being launched into the optical fiber core, it is sufficient to direct all of the power of such light all over the grating region along a single direction substantially coincident with the aforementioned path and including the requisite angle α with the longitudinal axis of the core, rather than having to distribute such power all around the optical fiber and, to the extent that such power is carried by light having a wavelength within the aforementioned narrow range around the center wavelength λ, a meaningful proportion of such directed light power will be redirected into the core for guided longitudinal propagation therein even though only a small portion of such light is redirected at each of the grating elements. This effect is attributable to the constructive interference between the partial light amounts which have been redirected at the respective grating elements with the partial light amounts redirected at the longitudinally consecutive ones of the grating elements. The constructive interference is not limited to a single value of the central wavelength λ; however, the angle of the external path that results in the constructive interference is peculiar to the respective central wavelength λ.

The arrangement described in the above patent application, as advantageous as it may be for some uses, has a considerable disadvantage that, inasmuch as the grating region occupies a finite and yet relatively significant length of the core and the partial light amounts redirected by the grating elements into the external path propagate substantially parallel to one another, the dimension of the external path that is parallel to the longitudinal core axis is substantially identical to the axial length of the grating region. To achieve efficient capture of the light emitted into the second path, the above patent application proposes the use of an external lens or of functionally similar external optical elements to concentrate or focus such partial light amounts onto a photodetector or another light receiver component. Conversely, light issued by an external source must be collimated prior to reaching the grating region and expanded to cover the entire grating region to efficiently launch light into the core, by external optics akin or identical to those described above. This complicates the structure of the arrangement, substantially increases its cost, and may result in alignment problems.

Turning now once more to Figure 1 of the drawing, it is to be mentioned first that the concepts shown therein (as well as in the remaining Figures of the drawing) are based on the principles described above. Here again, the grating elements 12 are inscribed in the core 10 by exposing the grating region of the latter to an interference pattern of two incident ultraviolet light beams; however, unlike in the situation described above, the grating 11 has additional quadratic refractive index variations impressed therein.

A direct way of inscribing the grating 11 of the type revealed in Figure 1 of the drawing in accordance with the

present invention is by exposing the waveguide or core 10 to incident ultraviolet radiation beams at least one of which has a suitable phase front curvature, for instance, as a result of passage of the affected incident beam through an appropriately configured lens. In this context, it is to be mentioned that the in-fiber Bragg grating 11 can be thought of, and modeled as, a linear-phased array. Refractive index variations redirect a small fraction of an incident bound mode into a radiation pattern that is determined by the grating element period tilt, and grating region length, the light wavelength, the waveguide cross section and the mode spectrum. If the grating period Λ is a constant, as it is in the arrangement of the above-discussed patent application, then the emission pattern is a narrow, conical diverging fan-shaped intensity distribution. In accordance with the present invention, this pattern is focused to a focal line in the near field by varying the grating period or wavenumber $K = 2\pi/\Lambda$. As indicated in Figure 1 of the drawing, a grating 11 having a linearly varying grating wavenumber or quadratic phase focuses the narrow diverging fan to a line focus at a point $P(x_o, z_o)$ in the longitudinal plane of the waveguide 10, thus creating the effect of a Fresnel lens. It is known, for instance, from the book by A. W. Snyder and J. D. Love entitled "Optical Waveguide Theory", Chapter 22, pp. 460 - 463, published by Chapman & Hall (1983), that weak index perturbations in a fiber core act as a distribution of point current dipoles, with phase and amplitude prescribed by the bound mode form and the grating period (or wavenumber) and strength. In the Fresnel zone, near to the fiber, the diffraction field $G(x_o, z_o)$ in the longitudinal plane can be expressed in terms of a Fresnel transform:

$$G(x_o, z_o) = \int_{-L/2}^{L/2} e^{j(K-\beta)x} \cdot e^{jknx^2/2z_o} \cdot e^{-jkn(xx_o/z_o)}\, dx$$

wherein n denotes the refractive index of the cladding, L is the length of the grating, k is the free space wavenumber, and β is the propagation constant of the bound mode.

If we let $K = K_o + knx/2z_o$, then

$$G(x_o, z_o) = \int_{-L/2}^{L/2} e^{j[(K_o-\beta) - knx_o/z_o]x} dx =$$

$$= \operatorname{sinc}\{[(K_o-\beta) - knx_o/z_o]L\} \approx$$

$$\approx \delta\{[(K_o-\beta) - knx_o/z_o]L\}.$$

It may be seen from the above that the light is brought to a line focus at $P(x_o, z_o)$ where the angle $\arctan(x_o/z_o)$ is determined by the values of K_o, and kn, as is the case in unfocused grating tap, and the position z_o is determined by the sweep rate of K. Given the reciprocal effect of the grating 11, if light of the proper wavelength issued by an external source is caused to pass through and focus onto the focal line $P(x_o, z_o)$ on its way to the grating 11, the latter will redirect or launch such light into the waveguide 10 for longitudinal propagation therein.

Similar focusing effect of the grating 11 is achieved if at least the grating region of the optical fiber or waveguide 10 is bent along a circular arc or any other suitable concave curve, either while the grating 11 is being written by exposure to the incident ultraviolet radiation beams symmetrical with respect to the plane extending at the angle α relative to a tangent to the longitudinal axis of the waveguide 10 at the center of the grating 11, or during the use of the waveguide after the grating 11 has been inscribed with the waveguide 10 extending along a straight course, as indicated in Figure 2 of the drawing. Here, the phase variation is introduced by bending the waveguide 10 into a circular

arc having a radius of curvature ρ_c.

When the grating period and tilt are set to redirect the light perpendicularly of the waveguide axis, the bending of the fiber focuses the pattern along a line at $\rho_f = \rho_c$.

Figure 3 of the drawing illustrates an optical arrangement that utilizes two waveguides 10 and 10' of the type described above, that is, each provided with the varying phase grating 11 or 11', one for illuminating an object 13 situated at and around the focal line $P(x_o, z_o)$ thereof, and the other for capturing light passing through (such as in measuring turbidity or the like) or radiated by (such as in measuring fluorescence) the object 13. The gratings 11 and 11' may both redirect light of the same wavelength, or each may redirect light of a different wavelength, depending on the parameter being measured. It will be seen that the amount of light received by the other of the waveguides 10 and 10' is an indication of the magnitude of the parameter being measured.

The arrangements as described so far focus the emitted light escaping from the waveguide 10 to a focal line. However, as alluded to before, the thus escaping light forms a fan spreading in the circumferential direction of the waveguide 10 when the latter is constituted by an optical fiber. Under some circumstances, however, it may be desirable to focus such escaping light to a focal point rather than to a focal line. This can be accomplished, especially if the waveguide 10 is a multimode waveguide, in a manner depicted in Figure 4 of the drawing, where it is indicated that at least partial Fresnel focusing can also be achieved in the plane orthogonal to the original Bragg plane by imposing a secondary quadratic phase variation into the waveguide 10 by exposure of the latter at the grating region 11 to another pair of interfering ultraviolet light beams. A graph of refractive index variation across the waveguide 10, taken on line A - A of Figure 4, is presented in Figure 5.

A particular advantage of the unidirectional focused redirection is not only the removal of at least a significant amount of the light of the selected narrow wavelength band around λ from the spectrum allowed to propagate through the waveguide 10 beyond the grating region 11 when the latter is being used for tapping light out of the fiber core 10, or insertion of such light into the core 10 when the grating region 11 serves to launch light into the fiber 10, but also, and possibly more importantly, an easy capture of the tapped-out redirected light in the narrow wavelength band around λ after its escape from the fiber 10 at the grating region location that may be situated a considerable distance from either one of the ends of the fiber 10, or easy insertion of such light into the fiber core 10 at such remote location, without the use of any external lenses or similar external focusing arrangements. Thus, the grating region 11 including the inclined grating elements 12 of the present invention constitutes a wavelength selective tap in the optical fiber 10 and also simultaneously focuses such light to a focus (either a focal line or a focal point) when used as a tap, or launches external light passing through such a focus on its way to the grating 11 into the waveguide 10 for longitudinal propagation therein.

While the present invention has been illustrated and described as embodied in a particular construction of an optical waveguide and associated equipment, it will be appreciated that the present invention is not limited to this particular example; rather, the scope of protection of the present invention is to be determined solely from the attached claims.

Claims

1. A light redirecting and focusing grating optical waveguide comprising:

a) an optical waveguide having two spaced end portions, and including at least a waveguiding portion (10) of a solid material capable of guiding light between said end portions in a first path extending along a predetermined axis;

b) at least one grating region (11) located at said waveguide portion (10) at a location remote from said end portions and having a multitude of grating elements (12) spaced along said axis, the spacing of said elements varying along said axis or said axis being curved in such a manner as to redirect light reaching said grating elements between said first path and at least one second path extending externally of said waveguide and diverging between a focus situated at a predetermined distance from said optical waveguide and said grating region;

characterized in that

c) said grating elements (12) are constituted by embedded axially successive refractive index variations extending through said solid material; and in that

d) in the plane of said first path and said at least one second path said grating elements (12) extend at an oblique angle relative to said axis.

2. An optical waveguide light redirecting and focusing arrangement comprising a light redirecting and focusing grating optical waveguide according to claim 1, and further comprising :

e) first optical means for directing light into one of said first and second paths and toward said grating region for redirection by said grating elements into the respectively other of said second and first paths; and
f) second optical means for capturing the light propagating in said other path.

3. A method of forming an embedded optical light redirecting and focusing grating (11) in a selected region of an elongated solid portion (10) of an optical waveguide, comprising the steps of:

a) forming two mutually coherent beams of ultraviolet radiation at least one of which has a curved phase front; and
b) directing the two beams transversely onto the solid portion at respective angles of incidence selected such that the beams are symmetrical relative to a plane extending at an oblique angle relative to the longitudinal axis of the solid portion so that the two beams so as to coherently interfere with one another generate an interference pattern having intensity peaks that extend into and through said selected region, the interference pattern causing refractive index changes in said solid portion, thereby forming a multitude of permanently embedded grating elements (12) spaced along said axis, the spacing of said elements varying along said axis in such a manner as to redirect light reaching then between a first path extending longitudinally through the solid portion (10) and at least one second path extending externally of the waveguide and diverging between a focus situated at a predetermined distance from said waveguide and said selected region, the grating elements (12) extending through said solid material at said oblique angle to said axis.

4. A method of forming an embedded optical light redirecting and focusing grating in a selected region of an elongated solid portion (10) of an optical waveguide, comprising the steps of:

a) forming two mutually coherent beams of ultraviolet radiation;
b) directing the two beams into a spatial region at such respective angles as to be symmetrical relative to a plane of symmetry with attendant formation of an interference pattern having intensity peaks extending parallel to said symmetry plane in said spatial region;
c) placing the selected region into said spatial region in such an orientation that said plane of symmetry extends at a predetermined oblique angle with respect to an axis of the solid portion substantially centrally of the selected region for said interference pattern to extend into and through the solid portion with attendant formation of grating elements (12) constituted by periodically repetitive refractive index variations in the selected region (11) dependent on the intensity variations of said interference pattern the grating elements (12) extending through said solid portion at said oblique angle to said longitudinal axis;
d) positioning the selected region at a location of use; and
e) causing said selected region to extend along a curved course during one, and a straight course during the other, of said placing and positioning steps such that during the use thereof at said location of use the spacing of said elements varies along said axis or said axis is curved in such a manner as to redirect light reaching them between a first path extending longitudinally through the solid portion and at least one second path extending externally of the waveguide and diverging between a focus situated at a predetermined distance from said waveguide and said selected region.

Patentansprüche

1. Optischer Wellenleiter mit Lichtumlenk- und Fokussiergitter, umfassend:

a) einen optischen Wellenleiter mit zwei voneinander beabstandeten Endabschnitten, und mit mindestens einem Wellenleiterabschnitt (10) aus einem festen Material, welches in der Lage ist, Licht zwischen den Endabschnitten in einem ersten Weg entlang einer vorbestimmten Achse zu führen;

b) mindestens eine Gitterzone (11), die sich an dem Wellenleiterabschnitt (10) an einer Stelle entfernt von den Endabschnitten befindet und eine Mehrzahl von Gitterelementen (12) enthält, die entlang der Achse beabstandet sind, wobei der Abstand dieser Elemente sich entlang der Achse ändert oder die Achse in der Weise gekrümmt ist, daß Licht, welches die Gitterelemente erreicht, zwischen dem ersten Weg und mindestens einem zweiten Weg, der sich außerhalb des Wellenleiters erstreckt, umgelenkt wird und zwischen einem in

einem vorbestimmten Abstand von dem optischen Wellenleiter befindlichen Fokus und der Gitterzone divergiert;

dadurch gekennzeichnet, daß

c) die Gitterelemente (12) gebildet werden durch eingebettete axial aufeinanderfolgende Brechungsindex-Änderungen, die sich durch das feste Material erstrecken, und daß

d) in der Ebene des ersten Wegs und des mindestens einen zweiten Wegs die Gitterelemente (12) sich unter einem schrägen Winkel relativ zu der Achse erstrecken.

2. Lichtumlenk- und Fokussieranordnung in Verbindung mit einem optischen Wellenleiter, umfassend einen optischen Wellenleiter mit Lichtumlenk- und Fokussiergitter nach Anspruch 1 und weiterhin umfassend:

e) eine erste optische Einrichtung zum Leiten von Licht in einen von dem ersten und dem zweiten Weg und in Richtung der Gitterzone zwecks Umlenkung durch die Gitterelemente in den jeweiligen anderen von dem zweiten und dem ersten Weg; und

f) eine zweite optische Einrichtung zum Einfangen des in dem anderen Weg sich ausbreitenden Lichts.

3. Verfahren zum Ausbilden eines eingebetteten Umlenk- und Fokussiergitters (11) für optisches Licht in einer ausgewählten Zone eines langgestreckten festen Abschnitts (10) eines optischen Wellenleiters, umfassend die Schritte:

a) Bilden von zwei kohärenten Ultraviolett-Strahlen, von denen mindestens einer eine gekrümmte Phasenfront besitzt; und

b) Lenken der zwei Strahlen quer auf den festen Abschnitt unter jeweiligen Einfallwinkeln, die derart gewählt sind, daß die Strahlen symmetrisch bezüglich einer Ebene verlaufen, die sich unter einem schrägen Winkel relativ zu der Längsachse des festen Abschnitts erstreckt, so daß die beiden Strahlen kohärent miteinander interferieren und ein Interferenzmuster mit Intensitätsspitzen erzeugen, die sich in und durch die ausgewählte Zone erstrecken, wobei das Interferenzmuster Brechungsindexänderungen innerhalb des festen Abschnitts hervorruft, um auf diese Weise eine Mehrzahl von permanent eingebetteten Gitterelementen (12) zu bilden, die entlang der Achse beabstandet sind, wobei die Beabstandung der Elemente sich entlang der Achse in der Weise ändert, daß Licht, welches dann zwischen einem ersten Weg, der sich in Längsrichtung durch den festen Abschnitt (10) erstreckt, und mindestens einen zweiten Abschnitt, der sich außerhalb des Wellenleiters erstreckt, umgelenkt wird und zwischen einem von dem Wellenleiter einen vorbestimmten Abstand aufweisenden Fokus und der ausgewählten Zone divergiert, wobei die Gitterelemente (12) sich durch das feste Material unter dem schrägen Winkel bezüglich der Achse hindurcherstrecken.

4. Verfahren zum Ausbilden eines eingebetteten Umlenk- und Fokussiergitters für optisches Licht in einer ausgewählten Zone eines länglichen festen Abschnitts (10) eines optischen Wellenleiters, umfassend die Schritte:

a) Bilden von zwei kohärenten Ultraviolett-Strahlen;

b) Lenken der beiden Strahlen in eine Raumzone unter solchen Winkeln, daß sie relativ zu einer Symmetrieebene symmetrisch sind, einhergehend mit der Entstehung eines Interferenzmusters mit Intensitätsspitzen, die parallel zu der Symmetrieebene in der Raumzone verlaufen;

c) Plazieren der ausgewählten Zone in der Raumzone in einer solchen Orientierung, daß die Symmetrieebene sich unter einem vorbestimmten schrägen Winkel bezüglich einer Achse des festen Abschnitts etwa mittig bezüglich der ausgewählten Zone erstreckt, damit sich das Interferenzmuster in den festen Abschnitt und durch ihn hindurch erstreckt, einhergehend mit der Entstehung von Gitterelementen (12), die gebildet werden durch periodisch wiederholte Brechungsindexänderungen in der ausgewählten Zone (11) in Abhängigkeit der Intensitätsschwankungen des Interferenzmusters, wobei die Gitterelemente (12) sich durch den festen Abschnitt unter dem schrägen Winkel bezüglich der Längsachse erstrecken;

d) Positionieren der ausgewählten Zone am Einsatzort; und

e) Veranlassen, daß die ausgewählte Zone sich bei dem einen der Schritte des Plazierens und Positionierens entlang einer gekrümmten Bahn erstreckt, während sie sich während des anderen der beiden Schritte entlang einer Geraden während ihres Einsatzes am Einsatzort erstreckt, wobei die Abstände der Elemente sich entlang der Achse ändern oder die Achse in der Weise gekrümmt ist, daß Licht, welches sie zwischen einem ersten Weg, der in Längsrichtung durch den festen Abschnitt verläuft, und mindestens einem zweiten Weg, der sich außerhalb des Wellenleiters erstreckt, umgelenkt wird und zwischen einem eine vorbestimmte Entfernung von dem Wellenleiter aufweisenden Fokus und der ausgewählten Zone divergiert.

Revendications

1. Un guide d'ondes optiques à réseau, réorientant et focalisant la lumière, comprenant :

a) un guide d'ondes optique ayant deux parties d'extrémités espacées et comprenant au moins une partie de guidage d'onde (10), réalisée en un matériau solide, pouvant guider la lumière entre lesdites parties d'extrémité, dans un premier chemin s'étendant suivant un axe prédéterminé;

b) au moins une région de réseau (11) située sur ladite partie de guide d'ondes (10), en un emplacement distal vis-à-vis desdites parties d'extrémité et ayant une pluralité d'éléments de réseau (12), espacés suivant ledit axe, l'espacement entre lesdits éléments allant en variant sur ledit axe ou bien ledit axe étant incurvé pour rediriger la lumière atteignant chacun desdits éléments de réseau entre ledit premier chemin et au moins un deuxième chemin s'étendant de façon extérieure audit guide d'ondes et divergeant entre un foyer situé à une distance prédéterminée dudit guide d'ondes optique et de ladite région de réseau;

caractérisé en ce que

c) lesdits éléments de réseau (12) sont constitués d'éléments noyés s'étendant axialement, présentant des variations d'indice de réfraction successives dudit matériau massif; et en ce que

d) dans le plan dudit premier chemin et dudit au moins deuxième chemin, lesdits éléments de réseau (12) s'étendent sous un angle oblique par rapport audit axe.

2. Un agencement de réorientation et de focalisation de la lumière utilisant un guide d'ondes optique, comprenant : un guide d'ondes optique à réseau réorientant et focalisant la lumière, selon la revendication 1, et comprenant, en outre, :

e) des premiers moyens optiques destinés à orienter la lumière dans un desdits premiers et deuxième chemins et en direction de ladite région de réseau, afin de produire une réorientation à l'aide desdits éléments de réseau, respectivement l'autre parmi lesdits deuxièmes et premiers chemins; et

f) des deuxièmes moyens optiques destinés à capter la lumière se propageant dans ledit autre chemin.

3. Un procédé de formage d'un réseau de réorientation et de focalisation de lumière, par voie optique, noyé dans une région sélectionnée d'une partie (10) solide allongée d'un guide d'ondes optique comprenant les étapes consistant à :

a) former deux faisceaux mutuellement cohérents de rayonnement ultraviolet dont au moins l'un présente de phase incurvé; et

b) diriger les deux faisceaux transversalement sur la partie solide, sous des angles d'incidence respectifs sélectionnés de manière que les faisceaux soient symétrique par rapport à un plan passant par un angle optique par rapport à l'axe longitudinal de la partie solide, de manière que les deux faisceaux interfèrent de façon cohérente l'un avec l'autre, de manière à générer un motif d'interférence ayant des pointes d'intensité s'étendant dans et à travers ladite région sélectionnée, le motif d'interférence provoquant une variation de l'indice de réfraction dans ladite partie solide, de manière à former une pluralité d'éléments de réseau (12) noyés de façon permanente, espacés en suivant ledit axe, l'espacement entre lesdits éléments allant en variant suivant ledit axe, de manière à réorienter la lumière les atteignant, entre un premier chemin, s'étendant longitudinalement et passant par la partie solide (10), et au moins un deuxième chemin, s'étendant en extérieur

du guide d'ondes et allant en divergeant entre un foyer situé à distance prédéterminée vis-à-vis dudit guide d'ondes et ladite région sélectionnée, les éléments de réseau (12) s'étendant à travers ledit matériau massif, suivant ledit angle oblique vis-à-vis dudit axe.

4. Un procédé de formage d'un réseau de réorientation et de focalisation de lumière, par voie optique, noyé dans une région sélectionnée d'une partie (10) solide, allongée, d'un guide d'ondes optique comprenant les étapes consistant à :

a) former deux faisceaux cohérents de rayonnement ultraviolet;

b) diriger les deux faisceaux dans une région spatiale, sous des angles respectifs, tels qu'ils sont symétriques par rapport à un plan de symétrie, avec une formation afférente de motifs d'interférence ayant des pointes d'intensité s'étendant parallèlement audits plans de symétrie dans ladite région spatiale;

c) placer la région sélectionnée dans ladite région spatiale, sous une orientation telle que ledit plan de symétrie s'étend sous un angle optique prédéterminé par rapport à un axe de la partie solide, sensiblement centralement vis-à-vis de la région sélectionnée pour ledit motif d'interférence et s'étendant dans et à travers ladite partie solide, avec formation afférente desdits éléments de réseau (12), constitués par des variations d'indices de réfraction, se répétant périodiquement, dans la région (11) sélectionnée, selon les variations d'intensité dudit motif d'interférence, les éléments de réseau (12) s'étendant dans ladite partie solide sous ledit angle optique vis-à-vis dudit axe longitudinal;

d) positionner la région sélectionnée à l'emplacement de l'utilisation; et

e) provoquer l'extension de ladite région sélectionnée suivant une trajectoire incurvée pendant une étape et une trajectoire rectiligne durant l'autre étape parmi lesdites étapes de placement et de positionnement, de manière que, durant son utilisation audit emplacement d'utilisation, l'espacement desdits éléments aille en variant suivant ledit axe, ou bien ledit axe étant incurvé à rediriger la lumière les atteignant entre un premier chemin s'étendant longitudinalement dans la partie solide et au moins un deuxième chemin s'étendant en extérieur du guide d'ondes et allant en divergeant entre un foyer situé à une distance prédéterminée vis-à-vis dudit guide d'ondes et de ladite région sélectionnée.

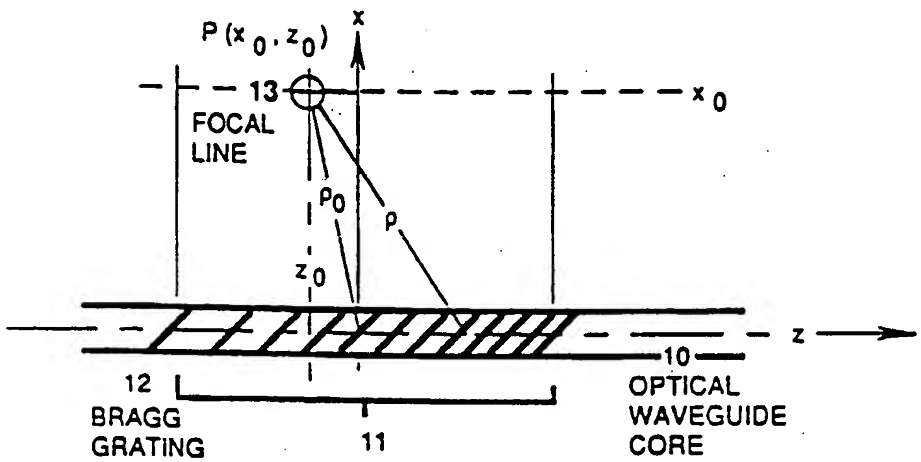

FIGURE 1

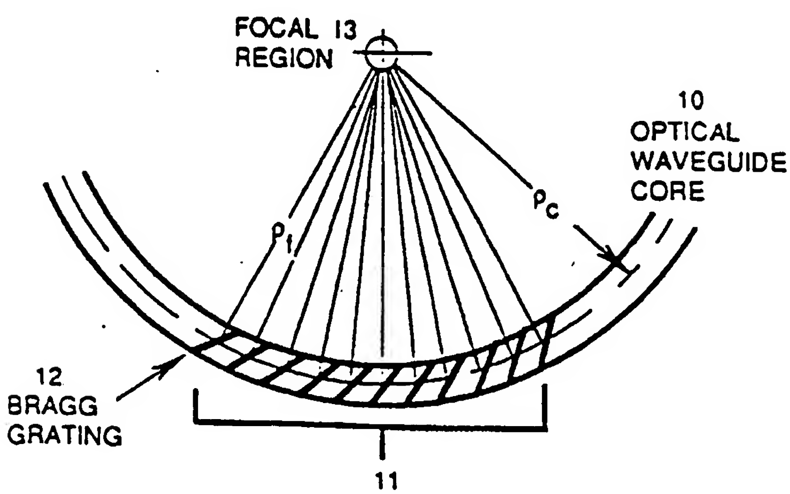

FIGURE 2

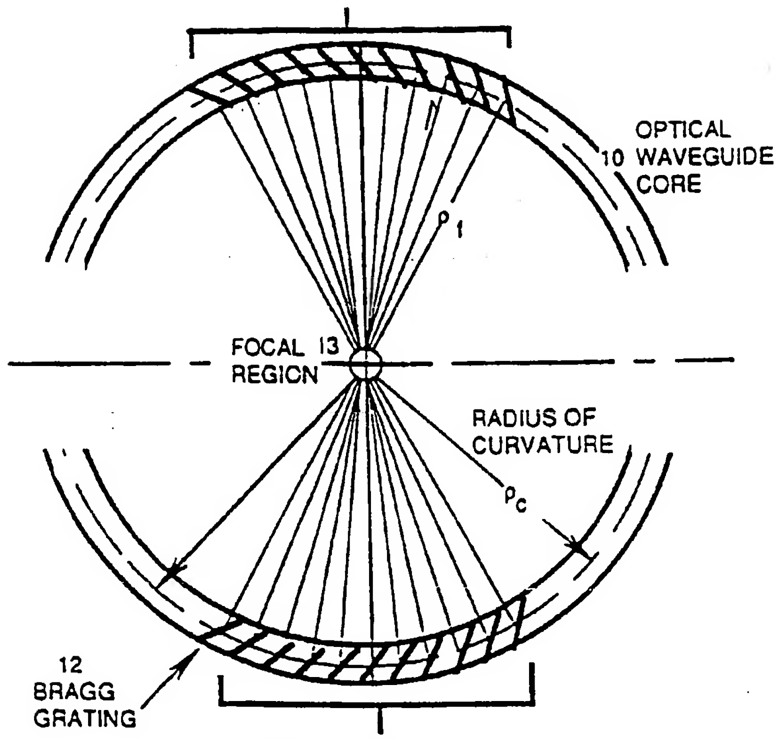

FIGURE 3

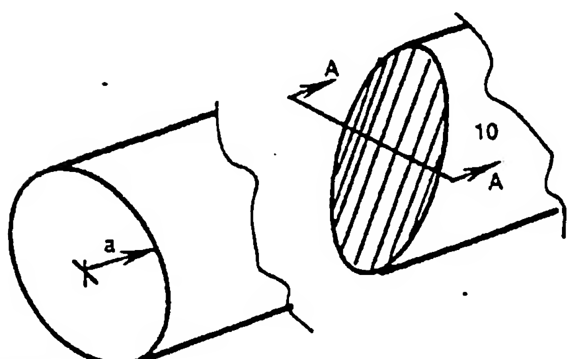

Figure 4

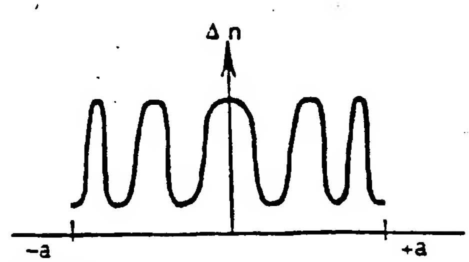

Figure 5